HEURISTIC APPROACHES TO TWO - DIMENSIONAL TRIM LOSS PROBLEM

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CERTIFICATE

This is to certify that the work embodied in the thesis entitled, "Heuristic Approaches to Two-Dimensional Trim Loss Problem," by T. Sattanathan has been carried out under my supervision and has not been submitted elsewhere for the award of a degree.

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ABSTRACT

This thesis develops solution procedures for the two-dimensional trim problem in which rectangular pieces are to be cut from, standard size rectangular plates so as to minimise the scrap produced. Two heuristic procedures using recursion has been developed. The heuristics developed have been tested on a practical problem in a large Engineering industry and results are encouraging. Computational performance of the heuristics with randomly generated problems have been carried out. The heuristic procedures yield reasonably good solutions and take substantially less time compared to algorithmic procedures. A graphical interface for the trim loss problem is also incorporated by which decision maker can appreciate and visualize the layout generated and interactive modify the layout making it a computer aided decision support system with wide applications.

CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

One of the important class of problems with primary significance to a variety of industries is the minimization of waste in the cutting patterns from standard stock which is limited in supply to meet customer orders. These problems may arise in the manufacture of a wide variety of materials, from cellaphane to metal sheets, but are particularly common in paper, glass and steel industries. These problems are referred to in OR literature by varying names like "Trim loss" or "Cutting Stock Problems". Their utility has prompted researchers to attempt solving such problems using a variety of methods.

The methods for solution can be classified broadly into two groups, viz. algorithmic and heuristic. An algorithmic or exact method for a problem is guaranteed to find the optimal solution for the problem. The exact methods have been found to be efficient for a narrow class of applications. The algorithmic methods used for solving trim loss problems falls mainly into well known categories of linear programming, branch and bound and dynamic programming. On the other hand, heuristic

methods cannot be guaranteed to find the optimal solution and often will not. A heuristic is acceptable in practice if the solution it produces is good enough, i.e. within tolerable range of deviation from optimal solution. Heuristic methods are employed when it is not feasible to employ algorithmic methods either due to non-availability or prohibitive computational cost. In general, a heuristic method is highly domain dependent, i.e. it will use information about particular problem to find optimal solution.

Trim loss problems can be classified into 1-dimensional, $1\frac{1}{2}$ - dimensional, 2-dimensional, $2\frac{1}{2}$ - dimensional and 3-dimensional problems depending on the relevance of the dimensional factors. 1-dimensional problems are found in lines of production where stocks of bar or rolls have to be cut into smaller pieces of same cross section; in these problems 1-dimension viz. length is relevant to the optimisation problem. In $1\frac{1}{2}$ - dimensional case, the length and width of the stock is relevant to the trim loss but one of the dimension is fixed and other is variable. In 2-dimensional case, the given stock is held as a rectangular sheet and customer requirement is rectangles of smaller dimension which is common in glass, steel and textile industries. In 3-dimensional case, three dimensions length, width and height are relevant to trim loss problem and is some times known as loading problem which may be defined as "..allocation of given items with known magnitude to boxes with constant capacity so as to minimize the number of boxes required ...".

The trim loss problem can be considered with various restrictions on input and output material and also on cutting technology.

In input restrictions availability of the material is primary concern. This can be viewed as the availability restrictions in the quantitative sense and as the material cost in the economic sense. The classification is shown in Figure 1.1.

- Input Material
  - Identical Size
  - Different Size
    - Stochastic
      - Taken from stock
      - Continuous flow of production
    - Deterministic
      - Standard sizes
      - Standard size and residual pieces

Fig. 1: Classification of the input material.

The output restrictions can be stated as type and quantity of the output produced that comply with demand. The classification of output material is shown in Figure 1.2.

- Output
  - Dynamic
  - Static
    - Satisfaction of demand
    - Under produc- tion
    - Over- production

Fig. 1.2: Classification of output.

The cutting and organisational restrictions for these problems may be in the form of meeting each customer's order size at a strech or in batches, number of pieces on a stock, orthogonal/non-orthogonal cutting etc.

With reference to rectangular cutting operations, if cuts are made parallel to edges then it is called "orthogonal cutting"and if made at any angle to edges then it is called "non-orthogonal cutting". (Fig. 1.3).

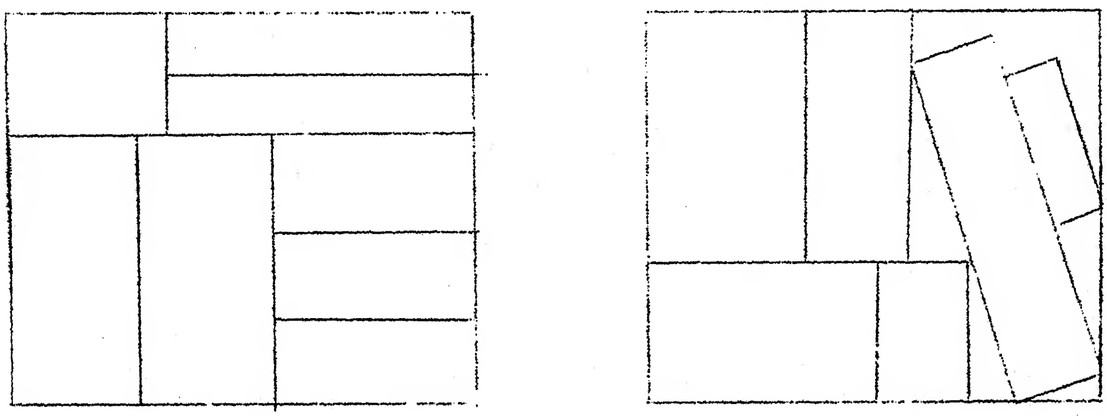

Fig. 1.3: Orthogonal vs. Non-orthogonal Cutting.

Orthogonal cutting patterns are further classified into two categories. If cutting technology enables only straight cuts to make from one edge of the material to the opposite one, as in the case when cutting paper with cutting machine or breaking panes of glass, then it is called "guillotine cutting." If it is permitted to discontinue the cut at any place in the material then it is called "inter-locked cutting"(Fig. 1.4).

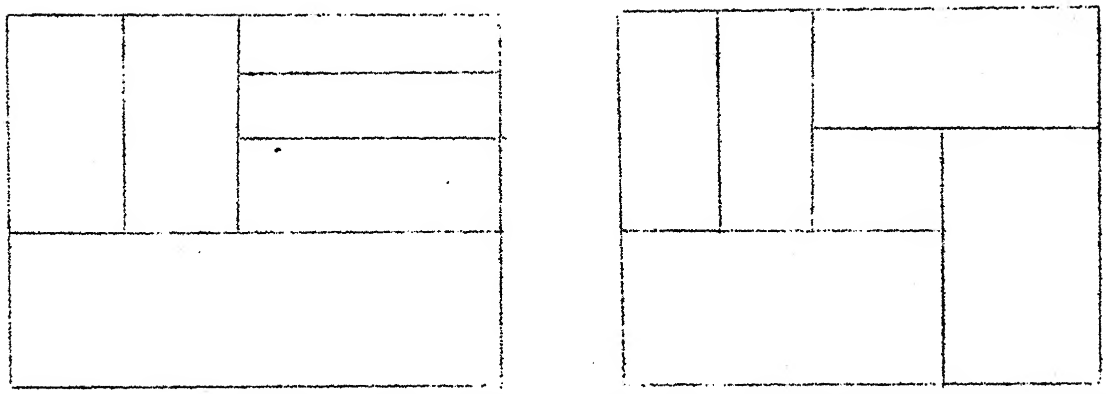

Fig. 1.4: Guillotine vs. Inter-locked cutting.

1.2 SCOPE OF THE THESIS

This thesis presents development of heuristics for a two-dimensional trim loss problem. Input stock is assumed to be available in standard sizes and residuals. The demand is assumed to be deterministic and static in nature. The customer demand has to be met exactly. It is also assumed that cuts are of "guillotine type". In addition this thesis develop procedures for interactive modification of layout generated if necessary, making it a computer aided decision support system having general applicability.

The software has been developed for aiding the user to modify the optimal pattern layout generated taking into consideration of defects, cutting restrictions etc. and make it natural to implement on shop floor. The commands for interactive modification is easy to use and a HELP command has been incorporated for benefit of the user.

The system has been implemented in PASCAL and using graphic package PLOT-10(IGL) which is available on the DEC-1090 system at IIT, Kanpur.

1.3 ORGANIZATION OF THE THESIS

This thesis has been organized as follows:

Chapter II surveys the OR/Management Science literature in which a review of earlier work done in the one-dimensional and two - dimensional trim loss problem has been reported.

Chapter III deals with heuristic procedures for two dimensional problem. Here two heuristic procedure LARGER and LONGER using recursion have been developed. The performance of these has been compared and an application to an engineering industry is reported.

Chapter IV deals with the Graphics Interface to the trim loss problem in which Geometric representation, command processing and interactive layout modification has been developed.

Chapter V deals with specific implementation details of system and describes the functions of various subprograms and their linkages in the main program of the system.

Chapter VI reports the conclusions and the suggestion for possible extension of the work reported in this thesis.

CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

Published literature on "trim loss" problems appeared around the early 1950's. Since then a number of works have been reported on one-dimensional and two-dimensional trim loss problem. A brief review of literature for one-dimensional and two-dimensional problems is described below.

2.2 ONE-DIMENSIONAL PROBLEMS

In a one-dimensional problem, only one dimension of the stock and the cut-pieces is significant. The situation occurs for example in cutting steel bars, paper rolls etc.

The first mathematical formulation of one-dimensional trim loss problem was done by Kantorvich [22]. Most of the one - dimensional problems were treated as Linear Programming Problems and solved by basic simplex method with some modification by Paul and Walters [24], Metzger [23], Eilson [11]. These methods were reported to be able to deal only with a small number of order sizes.

A significant improvement for handling large size problem was achieved by Gilmore and Gomory [13]. Their method involves solving at each pivot stage of simplex method, an auxiliary Knapsack problem to determine the successor solution.

Noting that considerable time is taken for achieving small improvements, they introduced a cut-off heuristic to terminate computation, if ten consecutive pivot stage together did not produce at least 0.1% reduction in waste.

In many practical situations trim-loss is not the only cost involved for cutting. Eiseman [12] developed an algorithm taking into account of resale value of scrap and machine sequencing Gilmore and Gomory [14] considered the application of their method to a problem in paper industry which also involved machine balancing.

Methods based on branch and bound was considered by Piere [25] for one-dimensional problem in which there is only one stock length. The method was then adapted to deal with restrictions on the number of pieces to be cut, costs related to setting up the cutting machinary and demands that are flexible within a given range.

In addition to algorithmic methods, heuristic methods were considered for problem reduction and saving of computation time. Hasler [16,17] developed a heuristic for reduction of the patterns by introducing aspiration level for occurrance of the cut piece. This method extended to problems with scheduling of pieces, was considered by Coverdale and Wharton [8].

Value heuristics based on delivery time, minimum acceptable quality and quality of slab being cut etc. were developed by Tilanus and Gerharat [26]. These values were used in a two-

stage Knapsack problem, and solved by Dynamic programming methods.

2.3 TWO-DIMENSIONAL PROBLEMS

In the two-dimensional case, the stock is a rectangular piece which has to be cut into small rectangular pieces, but with smaller dimensions. These problems occur in a wide variety of industries like steel, glass, card board paper etc. A number of attempts have been done on both exact (algorithmic) and heuristic methods for the two-dimensional case.

The first algorithmic method for solving two-dimensional problem was proposed by Gilmore and Gomory [15] who considered the problem as two-stage problem, and at each stage an auxillary Knapsack problem is solved if cutting patterns are of guillotine cut.

Tree search algorithms were proposed by Hertz [19] who developed a powerful recursive procedure with no constraints on the number of pieces to be cut when cuts are of guillotine cuts ; Christofides and Whitelock [7] developed a tree search algorithm when there is a constraint on the maximum number of pieces that have to be produced. However the performance of these algorithms for large size problems is not satisfactory in terms of computer time.

In addition to algorithmic methods, a number of heuristics have also been tried. Dyson and Gregory [9] adopted Gilmore and Gomory's method for solving problems with breaks

in production of pieces of an order and sequencing of the pieces using value based heuristic in which high values are assigned to "awkward pieces", and pieces that must be included in solution to avoid production breaks.

Another class of work in this area is the classification of the order rectangles into groups and then cutout the strips from the stock. Adamowicz and Albano [1,2,3] considered cutting stock problem of ship building industry. They grouped order rectangles into strips of one rectangle width using a problem reduction method to find an arrangement of strips which form a cutting pattern of required aspiration level. Hinxman [20] also grouped the order rectangles by using value heuristics by giving high value to most "awkward" pieces.

The problem of defects in stock was considered by Hahn [18], she considered three stage cutting of sheets using value heuristic with values of the form $a\,A_p + bA_p^2$ where A_p is area of the plate. The method used was iterative and dynamic programming was used to produce the cutting pattern in which sum of heuristic values are maximised.

All the methods which are mentioned previously were done for guillotine cut. Beasly [5] formulated the cutting stock problem and developed a non-guillotine cut tree search procedure for optimising the trim loss using subgradient optimisation with Lagrangian relaxation.

The advent of computer graphics helped persons working in this field to take better visualization of the layout and then interactively modifying the layout to overcome various restrictions. Albano [4] proposed an interactive system to improve the layout for a two-dimensional cutting stock problem in which solution obtained from the system can be modified through few commands available to user.

This thesis integrates the heuristic/analytical procedures and computer graphics to provide a versatile decision support tool for the user.

CHAPTER III

HEURISTIC PROCEDURES

3.1 INTRODUCTION

The constrained two dimensional cutting problems can be defined as follows:

There is a supply of standard rectangular plates generally known as stock of length L and width W which has to be cut into N_i, $i = 1,\ldots m$ smaller rectangular pieces known as cutpieces of dimension $w_i \times l_i$, $i = 1,\ldots, m$ using as few stocks as possible (i.e. minimizing the scrap) and meeting the customer demand.

Eventhough a number of exact solution procedures like that of Gilmore and Gomory are available, these procedures hardly take into account the special restrictions imposed by most of the practical problems. These restrictions may be with respect to production or coordination with other areas of planning. The limitations have led to the development of more and more solution approaches which are mostly heuristic. These are as a rule entirely devoted to special planning situations.

This thesis attempts the development of two heuristics for a particular constrained two dimensional trim loss problem arising out of an application in one of the leading public

sector undertaking in the country. The problem is to optimise the number of stocks to be used, thereby reducing the scrap and meeting exactly the customer demand.

In the first heuristics (LARGER) the cutpiece with largest area is selected first and the remaining pieces are allocated to the residual portion of the stock in a recursive manner. This process is repeated until cutpieces are exhausted or the area available in the stock is exhausted/insufficient to accommodate further pieces. The cuts are assumed to be guillotine cuts.

In the second heuristics (LONGER) the cut pieces with maximum length is selected first and the remaining pieces are allocated recursively in a manner similar to the procedure explained earlier for the LARGER heuristic.

The actual allocation methodology is explained in the next section.

3.2 GUILLOTINE CUTS

There is one type of orthogonal cutting in which cuts are made beginning from one side and traverse the material in straight line to other. This can be done either horizontally or vertically. These cuts made from one edge to another is called Guillotine cut. As this thesis works takes an application in an Engineering industry where cuts are of the Guillotine type, we limit ourselves to guillotine cut in this thesis.

3.3 RECURSIVE PROCEDURE

The recursive procedure used for allocation of piece on the stock is explained below.

From the list of cutpieces, a piece is selected for allocation depending on the heuristic used. After allocation of piece, stock can be cut vertically or horizontally.

In a horizontal cut, the cutting is made as shown in Figure 3.1. This cut leaves out two residual pieces on the stock, (1) and (2) as shown in the figure. It may be

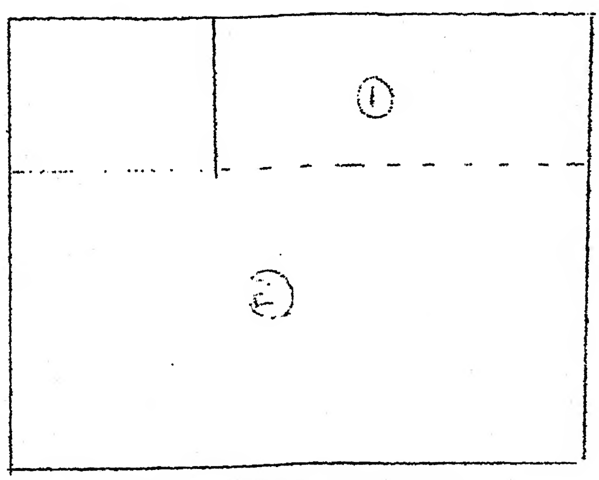

Fig. 3.1: Horizontal cut.

noted that one or both the pieces can degenerate when the length/width of the piece equals the corresponding dimension.

In a vertical cut, the cutting is made as shown in Fig. 3.2. The residual pieces obtained are marked as (3) and (4) in the figure.

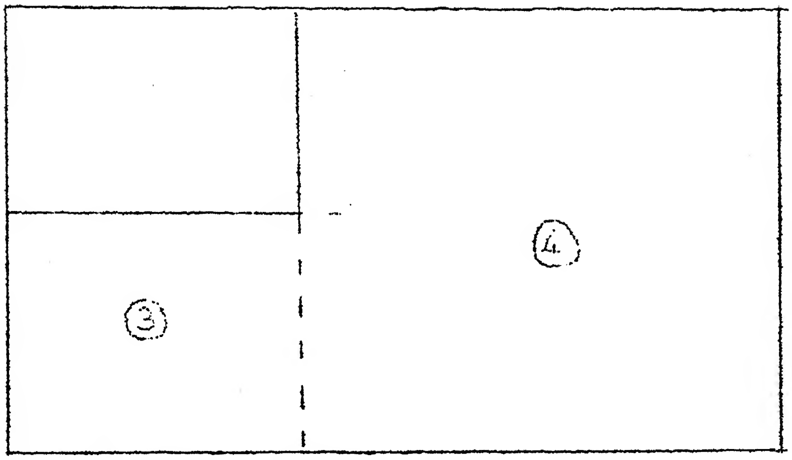

Fig. 3.2: Vertical cut.

Thus after an allocation of a piece on the stock, an L-shaped residual is obtained which can be considered as a combination of two rectangles depending on the cut made.

The residual of stock marked (1), (2), (3) and (4) are considered separately and allocation process is repeated recursively until cutpieces, are exhausted or area available in residual is exhausted/insufficient to allocate more pieces on the residual stock. In each level of recursive allocation, the selection of best cut is made which will give minimum scrap. The approach of recursive procedure is shown in Fig. 3.3.

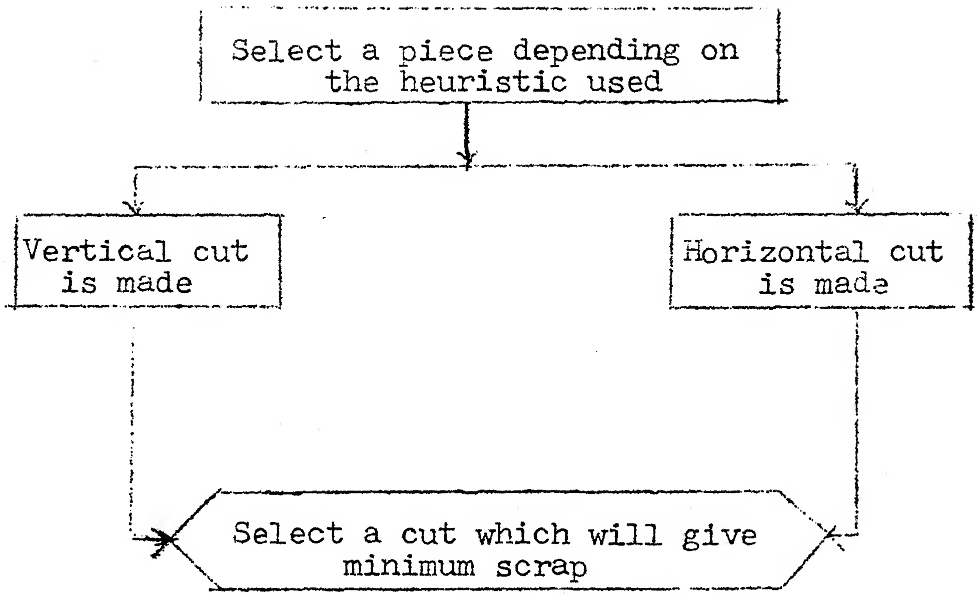

Fig. 3.3: Recursive procedure.

3.4 HEURISTIC 1 (LARGER)

This heuristic uses the criteria of selection of pieces on the basis of maximum area to be allocated first. For this a piece with the maximum area and of a size which can be accommodated in the given dimensions of the stock is selected, allocation process is repeated using recursive procedure explained previously for the given stock. For this stocks are considered one at a time. Further, once an acceptable solution has been found out for a stock, the solution will not be reconsidered. In other words the remaining decision does not have any influence on a subproblem solved previously. The process is repeated with the reduced number of cutpiece until all

3.5 HEURISTIC 2 (LONGER)

In this heuristic pieces with maximum length/width are selected first for consideration and allocation is made in same way as the previous heuristics (LARGER).

3.6 EXTENSION

An extension of recursive procedure has been applied on both the heuristics in which a given cut piece can be rotated by 90^{o}. The procedure checks for the best orientation of the all the cutpieces. At each level of the recursive procedure an orientation of the cutpiece which will give minimum scrap is selected.

3.7 APPLICATION TO A PRACTICAL PROBLEM

3.7.1 Description:

The trim loss problem occuring in one of the Engineering industry has been studied and found to be similar to the constrained two dimensional problem explained previously. The problem is the optimisation of the consumption of the materials for making boiler structures, which are made up of plates of different sizes. These plates have to be cut from standard size plates available in the market. The problem is to reduce the scrap or unused area, so as to optimise the consumption of standard plates.

3.7.2 Data:

The data regarding the stock sizes, cutpiece sizes and requirements of the cutplates for this practical problem are

shown in Table 3.1.

3.7.3 Results

The heuristic LARGER and LONGER are applied on the data of Table 3.1 and the results are shown in Table 3.2.

For the given data heuristic LARGER gives a waste rate of 13.8 for the stock size 1250 x 6300 mm and 10.8 for the stock size 1500 x 6300 mm while corresponding values by LONGER being 15.7 and 16.4 . Therefore it has been found that heuristic LARGER gives better solution than LONGER.

3.8 PERFORMANCE OF THE HEURISTICS

The heuristic that have been developed are tested for their performance through a randomly generated test data and the results are compared for two different types of stock 10 x 25 meters and 15 x 20 meters. A set of 100 pieces are generated randomly according to following assignment

length = integer (12 x random + 1)

width = integer (8 x random + 1)

where the values of the random is drawn from a uniform distribution in the range (0,1). The set of data used in the present thesis is shown in Table 3.3.

The experiments were conducted by selecting cutpieces i the multiples of 20 and waste rate for two heuristics are computed and shown in Table 3.4 and 3.5. The scrap area and

scrap rate per stock (in percentage) are reported under the column waste rate. The unutilized area in the last stock plate is not included on the assumption that it is reusable in future.

From the Table 3.4 we can see that for the stock 10 x 25 m, the scrap rate is found to decreasing as number of pieces are increased. The sudden increase in the scrap rate when number of pieces increased to 100 may be due to non-availability of smaller pieces in for filling of the stock completely. It has been also found that waste rate for heuristic LARGE is lesser than LONGER. In the case of stock size 15 x 20 m, the scrap rate is found to be varying from 0 to 1 for heuristic LARGER and 0.58 to 2.2 for longer as shown in Table 3.5. Even though in some cases heuristic LONGER performs better than heuristic LARGER, the heuristic LARGER gives better results for trim loss problem considered in the thesis.

Table 3.1: Stock and cut sizes for the practical problem.

Stock size available

1250 mm x 6300 mm
1500 mm x 6300 mm

Sl.No.	Cut pieces: Size (in mm)	Cut pieces: Requirement
1.	190 x 442	12
2.	190 x 878	8
3.	200 x 1446	4
4.	200 x 1870	16
5.	210 x 392	16
6.	300 x 2998	8
7.	300 x 3030	18
8.	300 x 3260	16
9.	300 x 3298	16
10.	302 x 1960	8
11.	320 x 2998	8
12.	370 x 2000	4
13.	370 x 3120	4
14.	846 x 1663	2
15.	846 x 5000	2
16.	860 x 144	4
17.	860 x 1663	4
18.	860 x 1736	4
19.	860 x 5000	8

Table 3.2: Results for the practical problem.

	Stock Size	
	1250 x 6300	1500 x 6300
<u>LARGER</u>		
No. of sheets	21	17
Waste (m^2)	22.85	17.34
Waste rate (percent)	13.82	10.8
No. of pieces in the last sheet	4	1
Area of these pieces (m^2)	1.16	0.37
<u>LONGER</u>		
No. of sheets	21	18
Waste (m^2)	25.93	27.82
Waste rate (percent)	15.7	16.4
No. of pieces in the last sheet	3	1
Area of these pieces (m^2)	4.3	1.41

Table 3.3: Pieces for test problems.

1-20	21-40	41-60	61-80	81-100
8x6	10x3	10x7	9x2	5x6
11x4	2x8	5x4	7x6	7x1
10x3	8x3	3x2	1x5	1x1
4x7	7x3	7x7	5x2	7x7
12x6	8x4	11x8	11x4	3x8
11x6	2x7	10x5	11x3	10x8
12x8	12x7	4x7	3x1	4x7
3x6	1x2	5x4	9x2	7x6
4x3	3x8	2x3	11x7	9x5
3x8	1x1	3x3	10x4	5x2
9x1	12x7	8x3	5x4	7x3
1x3	3x4	11x4	11x2	11x6
8x6	8x4	8x1	7x3	9x7
11x3	11x5	8x7	12x6	7x6
11x1	5x6	6x5	11x5	9x6
9x8	8x8	8x5	2x6	4x2
9x1	4x1	4x8	10x4	4x6
11x5	10x3	8x8	10x4	3x1
1x7	12x7	7x2	1x3	12x4
7x8	12x3	6x2	2x4	4x2

All dimensions are in meters.

Table 3.4: Results for Test problem with stock size 10 x 25

No. of pieces	20	40	60	80	100
Area of pieces	741	1420	2090	2673	3330
<u>LARGER</u>					
No. of sheets	3	5	8	10	13
Waste (sq. meter)	67	65	62	12	103
Waste rate	8.9	5.2	3.1	0.48	3.2
No. of pieces allocated in the last sheet	3	8	7	8	7
Area of these pieces (sq. meter)	58	235	153	185	183
<u>LONGER</u>					
No. of sheets	3	5	8	10	13
Waste (sq. meter)	57	58	65	42	70
Waste rate	7.6	4.6	3.25	1.68	2.2
No. of pieces allocated in the last sheet	1	8	6	9	7
Area of these pieces (sq. meter)	48	228	156	215	150

Table 3.5: Results for Test problem with stock size 15 x 20

No. of pieces	20	40	60	80	100
Area of pieces	741	1420	2090	2673	3330
LARGER					
No. of sheets	2	4	7	8	11
Waste (sq. meter)	4	4	21	0	8
Waste rate	0.6	0.3	1.0	0	0.24
No. of pieces allocated in the last sheet	6	10	1	17	3
Area of these pieces (sq. meter)	145	224	12	273	39
LONGER					
No. of sheets	2	4	7	8	11
Waste (sq. meter)	13	7	18	20	68
Waste rate	2.16	0.58	0.85	0.83	2.1
No. of pieces allocated in the last sheet	5	9	1	15	4
Area of these pieces (sq. meter)	154	227	9	293	99

CHAPTER IV

GRAPHICS INTERFACE

4.1 INTRODUCTION

The second subproblem dealt with in this thesis is a display of the solution generated by heuristic in a graphical terminal in which user can visualise how a layout is generated and modify the layout generated using simple commands. This problem can be sub divided as under:

- o Geometric Representation
- o Command processing
- o Interactive Modification commands

4.2 GEOMETRIC REPRESENTATION

Geometric representation of layout is one of the important problems for providing accurate model of the layout. Two dimensional pictorial data structures can be broadly classified into two categories [21] as follows.

Topological (or Polygon) Structure

The two-dimensional patterns can be described by points, lines and polygon are stored in terms of (x, y) co-ordinates.

Grid Structure

It divides a picture into a rectangular grid where each grid cell contains information about the attribute e.g. presence

or absence of an attribute or value of the elevation if it is 3 - dimensional representation.

In general, topological structures are more space efficient than grid structures, but problems like over-lapping of two rectangular polygons can be easily handled using a grid map. The topological structure has the strength of tracing line and can be applied to various applications.

As the problem is concerned with layout of rectangular cut pieces and system which is more oriented towards user, we have adopted topological representation of the layout in which (x, y) co-ordinate of piece which furthest distant from origin is used as representation. The orientation of the pattern is also stored in the form of array in which elements are represented in the form of binary numbers 0 - corresponding to same orientation as given in the input, or 1 - corresponding to direction in which given cut piece is rotated by 90^{o}.

4.3 COMMAND PROCESSING

For a software developed as a decision aid, command processing must be efficient and as simple as possible while allowing reasonable power of expression. Therefore commands for doing various interactive modifications are given in the form of self-explanatory menu from which user selectsparticular menu through which user has to modify the layout. In addition the user can sèlect a cut piece for shifting its location with the help of cursor, using a minimum number of simple commands.

4.4 INTERACTIVE MODIFICATION COMMANDS

For interactive modification of the layout, user is being provided with four modification commands; and two decision commands. If the layout generated by heuristic is acceptable to user the user need not have to use any of these commands. The four basic commands available to user for modification of the layout are: ROTATE, TRANSLATE, INSERT and DELETE specified cut pieces. DISPLAY command can be used to see the modified layout and AXIS command help the user in modifying the layout by drawing axes around the rectangular stock. The commands and their functions are:

1. ROTATE — to rotate the specified cut piece through 90^{o} about the centriod.
2. TRANSLATE — to move the specified cut piece to new position of centriod as specified interactively.
3. INSERT — to insert the specified number cut piece at a location specified by user graphically.
4. DELETE — to delete the pattern selected through graphical medium from the given layout.
5. AXIS — to draw axes along the rectangular stock with number of divisions on X and Y axes as specified by user.
6. DISPLAY — to display the modified layout on the terminal.

The patterns are numbered in the display for ready reference to help in modification. The present layout modification is implemented with commands being given one by one and nesting of commands have not been implemented.

CHAPTER V

SYSTEM DETAILS

5.1 INTRODUCTION

In this chapter we discuss the specific implementation details of the system including various subprograms and their structure and how they are linked together.

5.2 SYSTEM ORGANIZATION

The system has been implemented using an interactive approach, in which system interacts with user to accept the sizes of the stock and the cut pieces, and suggest a solution or layout as close to optimal as possible. It also allows the user to further modify the layout, taking into consideration special requirements of specified cut pieces or cutting restrictions.

The system flow chart is shown in Figure 5.1.

5.3 ELEMENTS OF THE APPLICATION CODE

The code for the system consists of three parts as explained below:

1) The main program and most of the procedures used for generation of the layouts using the heuristics have been wri'. in PASCAL. The facility of recursion supported by PASCAL has been extensively used in the heuristics.

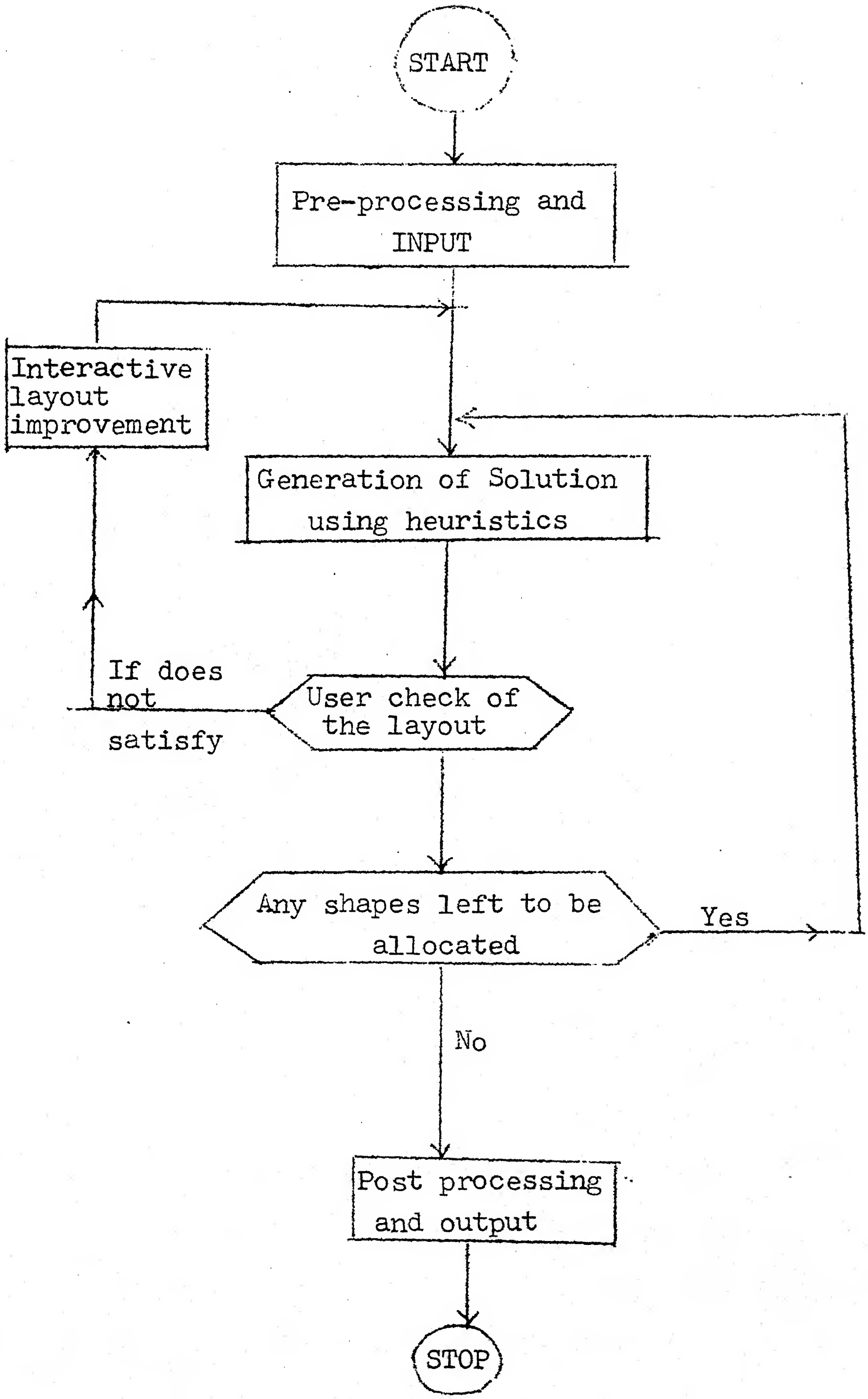

Fig. 5.1: System Flowchart.

2) Some of the subroutines are written in FORTRAN for graphic use. The graphical package Interactive Graphics Library (IGL) commercially known as PLOT-10 is used in the present system. This package is more powerful than GPGS system available in DEC - 1090.

The reasons for using FORTRAN subroutines instead of writing in same language as main program in PASCAL are.

- o that all IGL routines that are used, need to be declared as external procedures in PASCAL program which makes the code undesirably long.
- o that some of the FORLIB functions and other utilities which are accessed by FORTRAN calling programs are not easily accessible to PASCAL calling program on DEC-1090.
- o that a good and easy to use interface is available on this installation to call FORTRAN subroutines from a PASCAL program.

3) Interfacing between PASCAL calling program and FORTRAN subroutines is done using a program called FTNLNK. This should be the first procedure invoked in a PASCAL program.

The command for executing this system on DEC - 1090 is as follows:

EX TRIM.PAS, GRAPH.FOR, SYS: FTNLNK.REL,/SEA SYS: T

5.4 FUNCTIONS OF SUB-SYSTEM AND SUB PROGRAMS

5.4.1 Pre-Processing and Input Subsystem

This subsystem initialize the various subroutines and graphical terminals and invokes, the linking of FORTRAN program in PASCAL procedures. This subsystem also gives help for users, if needed by using a command HELP. After pre-processing is done, input can be given to the system interactively.

The list of subroutines called in this subsystem and their functions are explained below:

a) FTNLNK As some subroutines of the system are written in FORTRAN, this procedure has to be invoked first for linking the FORTRAN input/output operations to PASCAL main program and this subroutine is declared external FORTRAN in the PASCAL program.

b) SYSINITIAL This procedure initialize the linking nodes and the INITIALISE procedure. It also reset and rewrites various text filesand through GRINIT which is external procedure in FORTRAN.

c) SYSHELP This procedure gives online HELP to the user for running the system.

d) READDATA This procedure is used to interactively input sizes and requirements of cutpieces.

5.4.2 Generation of Heuristic Solution

This subsystem actually determines the heuristic solution/layout. The user can interactively select the heuristic LARGER or LONGER wing simple commands.

The system calls the procedure DOHURSTIC which in turn calls various procedures. The various procedures used in this subsystem and their functions are explained below:

a) DOHURISTIC — This procedure performs the heuristic generation of layout.

b) LARGER — This procedure is called by DOHURISTIC if cut-pieces are to be selected based on maximum area criterion.

c) LONGER — This procedure is called by DOHURISTIC if cut-pieces are to be selected based on maximum length criterion.

d) ZEROISE — When a cut-piece is selected the requirement of the cut-piece is reduced by one unit, thereby making it unavailable until SETPIECE is invoked.

e) SETPIECE — This procedure is called to restore the piece which is previously set a side by procedure ZEROISE

f) REMOVE — This procedure is called to remove the whole tree from a specified node from the solution list.

5.4.3 Interactive Modification

This is the subsystem which performs the interactive modification of the layout generated by DOHURISTIC. The output from procedure DOHURISTIC is converted to input to interactive procedure INTER.

The procedures used and functions of the procedures in this subsystem are explained below:

a) INTER This procedure is invoked as an external FORTRAN procedure in PASCAL program to branch to interactive modification of the layout generated by the Heuristics. In this subroutine the menu of various commands for interactive modification is given and this can be answered through a number or character as specified. Once the command needed by the user is recognised, it branches to particular subroutine for performing the modification. All interactive procedures are written in FORTRAN.

b) SELECT This procedure has been introduced to select interactively the cut-piece for any of the interactive modification.

c) CHECK This subroutine checks for overlapping of a given cutpiece by comparing it with layout of other pieces

d) PATDRW This subroutine is used for drawing the stock and cut pieces for display.

e) INSERT This subroutine is called by subroutine INTER if the user wants to insert a cut piece in the layout. For specifying the cutpiece, the user has to give number(s) of cutpiece from the list of cutpieces which he want to select. Once this is specified the cutpiece(s) the user has selected. The user can now select interactively the cutpiece he want to insert. If user is not satisfied, he can specify more piece(s) from which selection can be made. In the present implementation provision has been given for specifying a maximum of 3 pieces before selection is made final. The cut piece the user wants to select is done through subroutine SELECT. After selection of piece is completed the system comes with a message for selection of location where the piece has to be inserted. The user can select the place to insert using cursor position. Then the system checks through subroutine CHECK whether given piece can be fitted in position specified by the user. If it cannot be inserted, the system gives an error message, otherwise modified layout is displayed on the terminal.

f) DELETE This subroutine is called by subroutine INTER, if user wants to delete a cut piece from the given layout. The user can select the piece for deletion from the layout using the cursor and using the

subroutine SELECT. The specified pattern is deleted from the layout.

g) TRANS This subroutine is used for interactive modification for changing the position of a cut piece from one point to another. The modification is made on the assumption that change of position of the cut piece is with respect to centroid of the cut piece. When TRANS procedure is called, it calls for the user to select the cut piece for translation through the subroutine SELECT which the user can do by cursor movement. After a piece has been selected and identified, the user is asked to give location where the selected piece has to be moved. The user can specify the location using cursor and after that check is made overlapping of other cut pieces and translation is made if there is no over lapping and the modification layout is shown to the user. If there is a overlap, the system gives an error message and user can modify the location for translation if he wishes and the procedure can be repeated or terminated.

h) ROTATE This subroutine is called for rotating the specified cutpiece through 90° about its centroid. The user selects the cutpiece he wants to rotate through subroutine SELECT and layout when piece is rotated

for overlapping through subroutine CHECK before rotation is made. If there is over-lapping even when it is rotated, new modified layout is displayed, otherwise an error message is given.

i) DISPLY This subroutine has been introduced to help the user if he wants to see the layout of the cut piece on the stock.

j) AXES This subroutine can be used for finding coordinates of various cutpiece and can be used in layout modification.

5.4.4 Post Processing and Output:

This subsystem does the closing of the interactive graphics by calling GRFNSH and gives the output of the stock to be selected, cutpieces to be cut, and the coordinates of the cutpiece which has to be cut and its orientation which can be used for marking on stock for cutting.

5.5 SYSTEM SUMMARY

A prespective view of role and interaction of various program/procedures/subroutine can be had from Fig. 5.2.

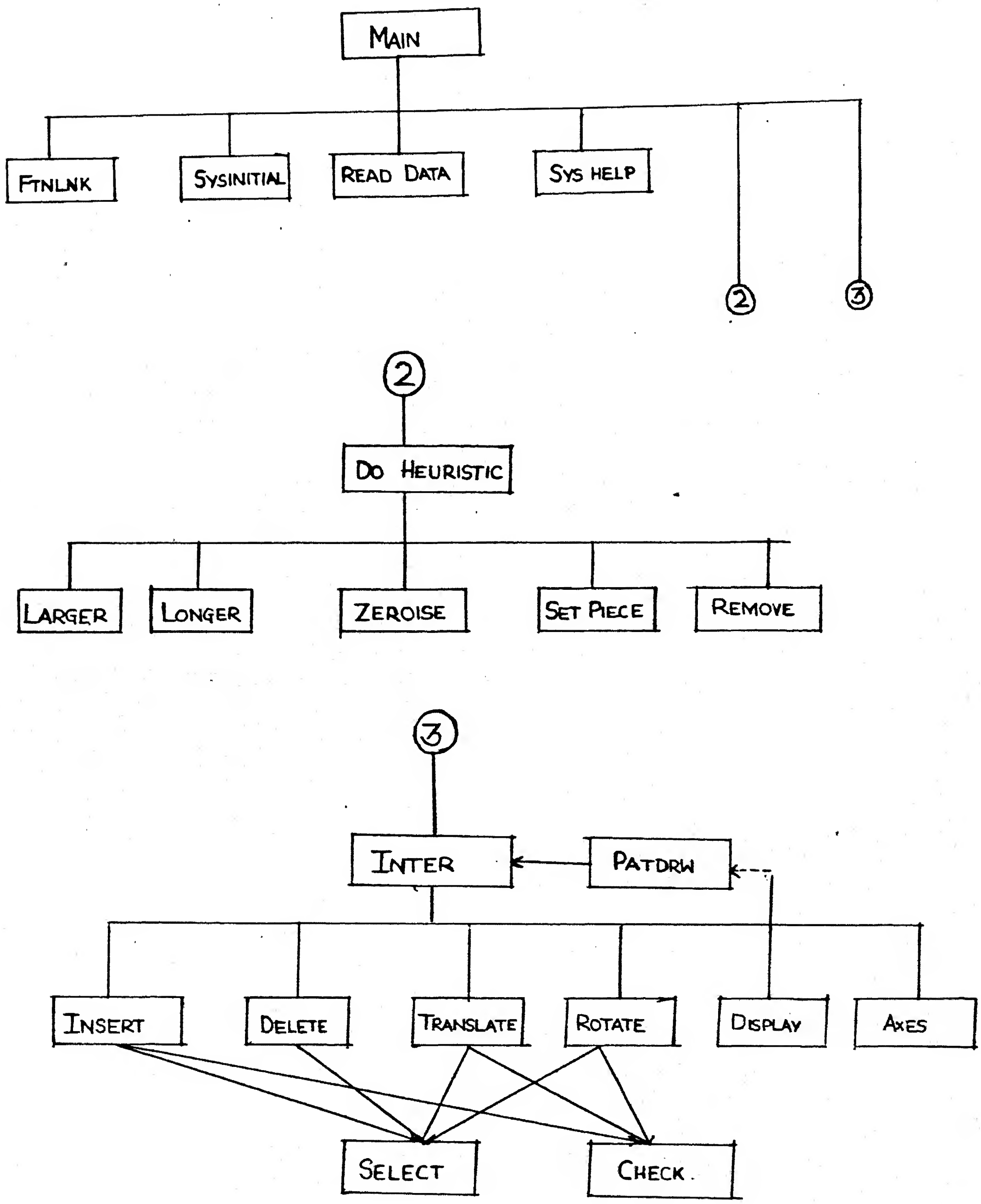

FIG 5.2 SYSTEM SUMMARY

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The present exercise is under-taken for a particular class of two-dimensional trim loss problem with an application inspired by one the leading engineering industries in the country. Two heuristic approaches using recursive procedures have been developed for solving these problems. The recursive procedure reported here is an improvement over the one proposed by Herz, which cannot be applied to constrained two-dimensional problems. Herz procedure does not limit the production of cut pieces in excess of demand. This causes over production of some of the cut pieces and under production for some other cut piece which is not desirable. Performance details of the heuristics has been reported. This has been favourably adopted by the industry where it was tried out earlier.

This thesis also provides an interactive modification of the layout by the decision maker. This interactive approach by making use of computer graphics and mathematical optimisation techniques helps the decision maker in taking better decision rather than spending more time on experimenting for the best way of cuts using trial and error methods.

6.2 SUGGESTION FOR FUTURE WORK

Further useful work can be carried out in two areas as given below:

6.2.1 Improvement in Layout Heuristics

As there is immense utility of methods for reduction of trim loss in industries, the following improvement can be looked into:

1) In the present implementation it is being considered that scrap is the main criteria for trim loss problem. If allowance is made for the excess produced over present demand (i.e. say 15 percent) the unused area can be converted into useful plates for future.

2) Another suggestion is the introduction of value based heuristic, i.e. the cut pieces which are necessarily to be produced are given higher value and once the demand is met they are assigned a low value. The optimization criteria will be maximization of overall value.

3) There is a class of problem similar to the trim loss problem called Assortment Problem in which selection of stock is made for the given cut piece. Normally in industries there is availability of different size of stocks and these problem can be considered as a variant of the trim loss problem for getting an optimum solution.

4) The heuristic may be improved to cater to situations where some portion of stock may have defects.

6.2.2 Improvements on Graphical Modification of Layout

In the present implementation, only few commands for interactive modification of the layout is given and these commands are operated with general graphical menu, one by one, The command processing may be improved to handle nested commands at a time with a better user comfort. Also graphical interface may be enhanced to give the user a scheme to give his own layout and check for the optimality.

The present exercise provides a basic frame work for a class of two dimensional trim loss problem which can be suitably modified to suit the nature and the requirements of an industry where it is going to be implemented.

REFERENCES

1. M. Adamowicz and A. Albano, A two-stage solution of the cutting stock problem, in: C.V. Freiman (ed.), Information Processing 71 (North-Holland, Amsterdam, 1972) 1086-1091.

2. M. Adamowicz and A. Albano, A solution of the rectangular cutting-stock problem, IEEE Trans.Systems, Man, Cybernetics, SMC-6 (1976) 302-310.

3. Albano and Orsini, A heuristic solution of the rectangular cutting stock problems, The Computer Journal, Vol. 23, No. 4, Nov. 1980, 338-343.

4. Albano, A method to improve two-dimensional layout, Computer Aided Design, Vol. 9, No. 1, January 1977, 48-52.

5. J.E. Beasley, An exact two-dimensional non-guillotine cutting tree search procedure, Operations Research, Vol. 33, No. 1, 49-64.

6. Bengt-Erik Bengtsson, Packing Rectangular Pieces - A Heuristic Approach, The Computer Journal, Vol. 25, No. 3, 1982, 353-357.

7. N. Christofides and C. Whitlock, An algorithm for two-dimensional cutting problems, Operations Res. 25 (1977), 30-44.

8. I. Coverdale and F. Wharton, An improved heuristic procedure for a nonlinear cutting stock problem, Management Sc. 23 (1976) 78-86.

9. R.G. Dyson and A.S. Gregory, The cutting stock problem in the flat glass industry, Operational Res. Quart. 25 (1974) 41-53.

10. H. Dyckhoff, H.J. Kruse, D. Abel and T.Gal, Trim loss and related problems, OMEGA, Vol. 13, No. 1, 59-72.

11. S. Eilon, Optimizing the shearing of steel bars, J. Mech. Eng. Sci. 2 (1960) 129-142.

12. K. Eisemann, The trim problem, Management Sci. 3 (1957) 279-284.

13. P.C. Gilmore and R.E. Gomory, A linear programming approach to the cutting-stock problem, Operations Res. 9 (1961) 849-859.

14. P.C. Gilmore and R.E. Gomory, A linear programming approach to the cutting-stock problem, Part II, Operations Res. 11 (1963) 863--888.

15. P.C. Gilmore and R.E. Gomory, Multistage cutting stock problems of two and more dimensions, Operations Res. 13 (1965) 94-120.

16. R.W. Haessler, An heuristic programming solution to a non-linear cutting stock problem, Management Sci. 17 (1971) B-793-B-802.

17. R.W. Haessler, Controlling cutting pattern changes in one-dimensional trim problems, Operations Res. 23, (1975) 483-493.

18. S.G. Hahn, On the optimal cutting of defective sheets, Operations Res. 16 (1968) 1100-1114.

19. J. Herz, Recursive computational procedure for two-dimensional stock cutting, IBM J. Res. Develop. 16 (1972) 462-469.

20. A.I. Hinxman, The trim-loss and assortment problems: A survey, European Journal of Operational Research 5 (1980) 8-18.

21. A.I. Hinxman, Problem reduction and the two-dimensional trim-loss problem, AISB Summer Conference Univ. of Edinburgh (1976) 158-165.

22. L.V. Kantorovich, Mathematical methods of organizing and planning production, Management Sci. 6 (1960) 366-422.

23. R.W. Metzger, Chap. 8, Stock Slitting , Elementary Mathematical Programming (Wiley, New York, 1958).

24. A.E. Paull and J.R. Walter, The trim problem: an application of linear programming to the manufacture of news-print paper, Presented at Annual Meeting of Econometric Society, Montreal, Sept 10-13, 1954, Abstract in Econometrica 23 (1955) 336.

25. J.F. Pierce, On the solution of integer cutting stock problems by combinatorial programming, Part I IBM Technical Report 36, Y02, Cambridge Scientific Center, Cambridge, MA 1966.

26. C.B. Tilanus and C. Gerhardt, An application of cutting stock in the steel industry, in K.B. Haley (ed.), Operational Research 75 (North-Holland, Amsterdam, 1976) 669-675.

27. Chock et al., Manipulating data structures in pictorial information systems, IEEE Computer, Vol.14, No. 11, Nov. 1981, 43-50.